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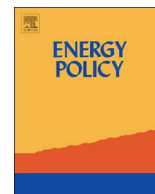
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An evidence-based approach for investment in rapid-charging infrastructure



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ABSTRACT

To date, real cost data for Electric Vehicle (EV) rapid charging infrastructure is largely missing in the literature, preventing development of economic models to encourage private investment and limiting policy decisions. A business model has been constructed using actual capital expenditure, operating costs and usage data from the Rapid Charge Network project (RCN) which can be used to assist future investment and policy decisions. The model is run under a wide spectrum of EV uptake scenarios to provide plausible answers to a variety of research, policy and investment questions, including minimum growth rates to break even under current policy. Using real-world data we have confirmed that a financial business opportunity does exist for investment in rapid chargers on main highways and have identified the operating area in which a profit can be made. However, since UK EV adoption is still at the Innovators stage in a niche market where innovations in technology, user practices, supporting infrastructure and functionality are still required to achieve wide user acceptance, the case is also made for continued fiscal incentives to encourage investment in rapid-charging infrastructure.

1. Introduction

Transport is a major source of greenhouse gas emissions which cause global climate change. The transport sector is the second largest contributor to greenhouse gas emissions in the European Union (EU), after the energy sector, but it continues to grow as a key enabler of economic prosperity and quality of life indicator. Therefore many European countries have introduced policy measures aimed at reducing transport emissions. The EU's Clean Power for Transport policy (European Commission, 2013) seeks to break Europe's dependence on oil for transport, and therefore sets out a package of measures to facilitate the development of a single market for alternative fuels for transport in Europe. The Deployment of the Alternative Fuels Infrastructure Directive 2014/94/EU (European Commission, 2014) requires Member States to adopt national policy frameworks for the market development of alternative fuels and their infrastructure.

In many countries EVs have been the major manifestation of alternative fuelled vehicles, with the UK being active in EV demonstra-

tion, roll-out and the introduction of supporting recharging infrastructure since 2010 (Herron and Wardle, 2015). UK ULEV sales continue to grow significantly, showing an 89% increase between 2014 and 2015, and the percentage of new car registrations rose from 0.2% in 2013 to 1% by 2015 (Department for Transport, 14 April, 2016). However, this is lower than in other countries which have been more successful in encouraging ULEV uptake, such as Norway at 18% and the Netherlands at almost 8% (ACEA, 2015). A significant increase in growth is still required to meet the UK Committee on Climate Change's (CCC) target in which ULEV market share reaches 60% by 2030 to enable the UK to meet its legally binding target for greenhouse gas reduction.

The UK Government believes that public chargers, also known as EVSE (Electric Vehicle supply equipment), are necessary to encourage and enable the uptake of EV and its Office for Low Emission Vehicles (OLEV) has therefore been incentivising public bodies to provide EVSE since 2011 (Office for Low Emission Vehicles, 2013). However, it is also keen to see private initiatives entering the marketplace and so has

Abbreviations: CAPEX, Capital expenditure; CCC, Committee on climate change; DNO, Distribution Network Operator; DSO, Distribution System Operator; EMSP, Electromobility service provider; EU, European Union; EV, Electric Vehicle; EVSE, Electric Vehicle Supply Equipment; ICE, Internal combustion engine; IRR, Internal rate of return; NCF, Net cash flow; NPV, Net present value; OLEV, Office for low emission vehicles; OPEX, Operating expenditure; RCN, Rapid Charge Network project; RFID, Radio Frequency Identification; TEN-T, Trans-European Network – Transport; ULEV, Ultra-low emission vehicle; ZCF, Zero Carbon Futures Ltd

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reduced its incentives for vehicles and recharging infrastructure from early 2016. Therefore, it is critical that credible business models are developed which will attract private investors into this marketplace. Ecotricity's Electric Highway network, a UK renewable energy supplier operating a national highway-based rapid charging network, is one such private initiative.

This is a classic “Chicken and Egg” conundrum. Consumers continue to state that a lack of public recharging facilities is a barrier to drivers deciding to purchase EV (Office for National Statistics, 2016). Drivers want the comfort of knowing they can recharge if and when required, even if they subsequently don't often use the public EVSE provided to meet those perceived needs (Franke and Krems, 2013; Hübner et al., 2013). Recharging infrastructure varies in cost depending upon desired capability (power, speed, outlets) and location. This paper focuses specifically on rapid EVSE located along main highways, which can charge EV to 80% state of charge in under 30 minutes using Mode 3 and Mode 4 connections, but currently cost the most to build. Moreover recharging infrastructure falls outside of the EV manufacturers' traditional area of activity, creating an ongoing debate about who is responsible for public EVSE provision and ownership. In order to enter the recharging infrastructure market potential private investors require some certainty about return, which has been difficult to provide to date in this nascent market. This paper directly addresses this by developing a full business case for investment in rapid EVSE using real-world costs, in order to assess the conditions required for success in different scenarios. The results are derived from an economic evaluation performed using data from the RCN project and the findings can be used to inform potential investors and policy makers alike.

The objective of this paper is to use real-world cost and recharging data to investigate whether a feasible financial business case exists for EVSE rapid charging on main highways, and to identify the conditions required for its success.

The article is divided into 9 sections. This introduction is followed by a synopsis of the RCN project which provided the data for this research, followed by the UK's policy position. The challenges facing the business model for public rapid charging infrastructure provision are then summarised, referring previous literature to RCN's findings. The roles of the various stakeholders in this business model are then described alongside the methodology used for the study. The inputs to the model and its assumptions are set-out and the findings are then described in more detail. Finally a series of conclusions are drawn to inform policy makers and potential investors. For ease of reference, the acronyms used in this paper are summarised in the footnote below.¹

2. The Rapid Charge Network (RCN) project

The data used to inform these results was generated by the Rapid Charge Network project (RCN). The project's ambition was to enable EV drivers to drive further, by installing EVSE in the form of 74 multi-standard rapid chargers during 2014 and 2015. The route covered 1100 km of Trans European Network-Transport (TEN-T) defined priority highways across the UK and into Ireland, as shown in Fig. 1. The route spans Great Britain from East to West, and South to North, crossing over the Irish Sea at Stranraer to Belfast and at Holyhead to Dublin in Ireland.

74 EVSE (rapid chargers) were installed for public use along main highways, at 65 privately owned sites including motorway services, fuel stations and large retail sites. 59 sites were located in Great Britain (England, Wales and Scotland), 3 in Northern Ireland and 3 in Republic of Ireland. EVSE was installed to enable access from both sides of the highway, enabling use for both long distance journeys and local travel.

The EVSE was equipped with three tethered charging outlets, to

provide IEC61851-1 Mode 4 DC charging at 44 kW power output through CHAdeMO and Combo 2 plugs, and Mode 3 AC charging at 43 kW through Type 2 plug as defined in IEC62191 standards. This multi-standard rapid charging approach breaks down a barrier to EV adoption by giving consumers confidence that they can recharge quickly where necessary, regardless of EV make or model (Blech and Kozdra, 2016). This EVSE approach benefits both EV drivers irrespective of EV model, and EVSE providers by maximizing their customer base whilst minimizing investment and space requirements. A maximum of two EVSE were located at any one site, and some sites subsequently experienced queues of EV waiting to recharge at busy times of day. Adding additional EVSE to cope with demand was outside the scope of the RCN project, but is now being addressed by the aggregator Ecotricity in the UK.

The chargers were operated under two existing free to use networks, Ecotricity's Electric Highway network in Great Britain and ESB's ecars network in Ireland, therefore there were no billing mechanisms in use during this study. Drivers were required to register with Ecotricity or ESB ecars, receiving an RFID card which provided access to all RCN chargers as part of the existing networks. A whitelist approval mechanism was used to enable Ecotricity and ESB ecars customers to roam between the two networks. Since the end of the RCN project, Ecotricity has introduced an app-based access system (without the need for upfront registration) and applied fees for the use of all its EVSE, including those installed by RCN, however this is outside of the scope of this paper.

The RCN study collected data from both EVSE and EV along the route, conducted questionnaires with over 200 EV drivers and installed data loggers in 40 EVs to monitor EV driving and charging behaviour, particularly distance travelled, energy efficiency, charging locations, frequency and energy drawn. Several of the EV manufacturers funding the project also supplied data, with the EV owners' consent, from their in-vehicle data loggers, providing a longitudinal data set that illustrated how driving and charging behaviour changed before and after rapid EVSE roll-out. In depth analysis of real-world driving and charging behaviour was therefore conducted, studying the changes as more chargers became available, alongside evaluating EV drivers' recharging requirements and willingness to pay for rapid charging services. One objective of the project was to assess the potential for investment in rapid charging networks, which utilized the EVSE data supplemented by EV driver questionnaire responses, and forms the basis of this paper.

The RCN project was funded by a consortium of four major EV manufacturers Nissan, BMW, Renault and VW plus Ireland's ESB ecars business, and was match funded by the EU's TEN-T programme (EC). Completing the project consortium were Zero Carbon Futures (ZCF) which delivered the project, and Newcastle University which performed the in-depth study work leading to the results presented here.

3. UK policy

Governments intervene where there is perceived to be market failure or in the early stages of market development to ensure that policy goals can be met. There is a risk that uncertainty will delay investment in new technologies such as ULEV, where public benefit is thought to outweigh private value to the company (Sierzchula et al., 2014). In addition, ULEV price and performance may be seen to compare negatively with the existing technology. However, it is vital that new technologies achieve sufficient early adopters to establish a market niche (Geels, 2002) so governments provide incentives to ensure there is sufficient demand.

The UK government has provided consumer incentives towards the purchase of ULEV cars (Office for Low Emission Vehicles, 2011) since 2011. The adoption of ULEV is essential to the UK government's goal of reducing greenhouse gas emissions to 50% of 1990 levels by 2025 (Committee on Climate Change, 2008) and reaching 80% reduction by

¹ Acronyms and definitions used in this paper.

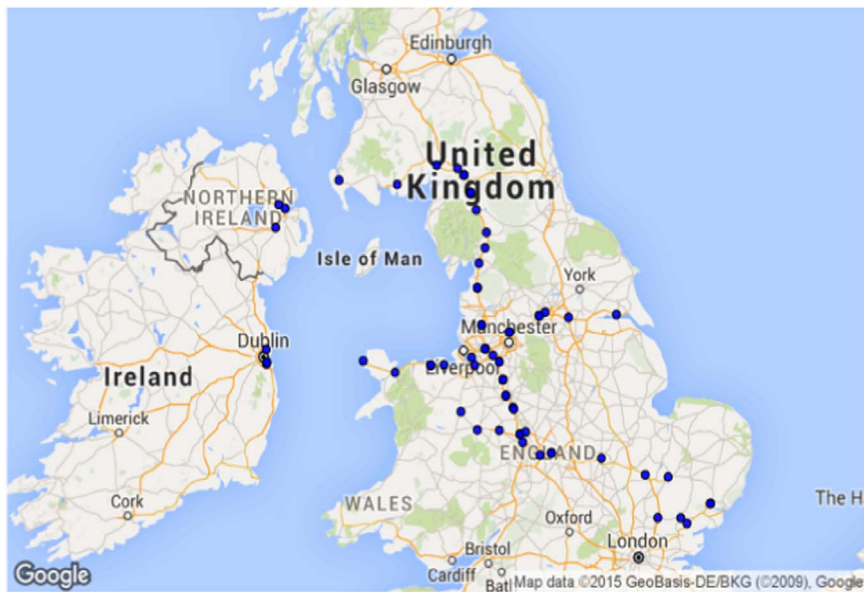


Fig. 1. Locations of RCN rapid chargers across the UK and Ireland.

2050. However, ULEV is still a new market where technology and customer acceptance are developing in parallel, and it is competing against the embedded ICE industry with its highly developed infrastructure and wide customer acceptance. ULEV is at the niche level in the Multi-Level Perspective (MLP) approach used in Technological Transitions theory (Geels, 2002), where radical innovation in technology, user practices, supporting infrastructure and functionality can occur with some protection from free market pressures.

ULEV sales continue to grow in the UK, but by Q3 2016 represented only 1.2% of new car sales and 0.23% of the licensed vehicle population (Department for Transport, Q3, 2016a; b). According to the Diffusion of Innovations theory (Rogers, 2003) this falls into the first phase of technology adoption called Innovators, covering adoption up to 2.5% of market share. Here new technologies may be classed as disruptive to routine tasks, a term which seems applicable to current ULEV range limitations and recharging practices. ULEV sales need to reach the next phase, Early Adopter, to drive the market forward from its niche status. Here adoption reaches 16% of market share and the consumers involved actively influence others and are usually willing to pay a premium for the latest technology.

But much higher ULEV adoption is required to make the desired contribution to emissions reduction, so demand must be stimulated to reach this point within the time required. The CCC's commissioned report "Pathways to High Penetration of Electric Vehicles" (Element Energy, 2013) produced a target that ULEV should represent at least 9% of all new car sales in the UK by 2020, which falls into the Early Adopter phase. The 60% target set for 2030 moves through Early Majority and into Late Majority adopters who are more risk averse and therefore unlikely to pay for new technology until it matches or exceeds the performance of the existing dominant technology. In Technological Transitions theory, this level of adoption would represent the onset of a new regime in transport systems.

At the current Innovators stage most potential EVSE investors consider the market insufficiently developed to provide an acceptable

return on investment, and therefore the UK government has been providing incentives for EVSE roll-out since 2010 (Office for Low Emission Vehicles, 2010; OLEV, 2016). However, because this is a complex adaptive environment, incentives can also have unintended consequences which distort the marketplace, presenting government with a further dilemma of how and when to cease intervention. Sierczula's study of the impact of consumer financial incentives on EV adoption (Sierczula et al., 2014) found that the availability of charging infrastructure was the strongest predictor of EV adoption, although he advocated coupling the provision of EVSE with financial incentives for vehicles in practise, since they are likely to be complementary. Therefore we suggest that the UK government should provide the market with a stable position on both vehicle and EVSE incentives until at least midway through the early adopter phase. Once at least 10% adoption has been achieved the government could then adopt a clear incentive reduction policy through the early majority phase, which the market can rely upon.

4. Rapid charging infrastructure business models

The challenges of the business model for EV charging infrastructure have been a subject of discussion for many years, however few figures have been publically available for analysis regarding actual investment costs and usage until now. The attractiveness of public EVSE to potential investors has been questioned (Kley et al., 2011; Madina et al., 2016; Schroeder and Traber, 2012) and for rapid EVSE in particular because of the large upfront costs. However, both drivers and public bodies continue to state that public EVSE is a requirement for private EV uptake, particularly stressing the need for rapid chargers because of their speed and therefore convenience (Element Energy, 2013).

Markkula et al. (2013) stated that investment in an individual rapid charger was viable based on estimated costs gained from market intelligence, and therefore proposed that rapid charger roll-out should

be one of the first actions taken to encourage EV adoption. This national approach has been adopted in a number of countries such as Estonia (ELMO), Ireland (ESB), Norway (Haugneland et al., 2016) and Germany (SLAM project) supported by public funding. By contrast in the UK Ecotricity, a privately financed company, has chosen to develop a national network of rapid chargers covering the motorway network at this early market stage and the RCN chargers in Great Britain now form part of this network. Interestingly however, Markkula's conjecture that pessimistic infrastructure costs were used in his early model has proved to be inaccurate, with RCN reporting significantly higher start-up costs in some locations where local conditions required additional works and/or new power connections.

New business models are required for e-mobility solutions because of the differences between electric and conventional Internal Combustion Engine (ICE) driven transport. Most EV are still more expensive to buy than ICE equivalents, and come with perceived operational limitations such as range, the need for education about how and where to recharge, and little experience of residual value. However they also have some major advantages, being cheaper to operate (in terms of re-fuelling and servicing costs), quieter, with better acceleration and zero tailpipe emissions at the point of use which supports wider air quality and emissions policy as well as CO₂ reduction. Some consumers may perceive recharging at home or work when the vehicle is parked anyway, as easier than the existing ICE refuelling methods. Therefore business models for the holistic e-mobility system are envisaged to promote a wider value proposition, which includes environmental and social considerations in addition to traditional financial concerns. Bohnsack et al. (2014) commented on the need to identify new sources of value for customers in the e-mobility system and to convert them into sources of economic value.

With this holistic approach comes a range of new stakeholders with differing motivations, opportunities, threats and likely conflicts of interest, which affect their behaviour within the e-mobility system (Bakker et al., 2014). Where their interests differ, their attitudes to financial return also differ. For example, some stakeholders such as grid operators act to mitigate the risk of further costs for grid reinforcement by aiming to control recharging behaviour, whereas electricity providers may seek to seize the commercial opportunity for increasing energy sales. Bakker described e-mobility in terms of an evolving socio-technical system where the conflicts between stakeholders' interests coupled with the stability of the existing ICE market make for an uncertain development path. Therefore continuing reliable policy support will be necessary in the medium term to enable e-mobility to flourish in order to deliver the environmental benefits required.

There are many policy options relevant to this goal and growing literature discussing their effectiveness and transferability (Davies et al., 2016). They include: direct vehicle subsidies aimed at private consumers and/or businesses (Gnann et al., 2015); car-sharing or multi-modal transport schemes; regulatory measures such as free parking or priority lane use; awareness raising programmes and support for EVSE provision. The choice of measures will differ depending upon the funder's influence and objectives (Bakker and Trip, 2013) and so it is likely that deployment of a mixture of policy actions will be most successful in increasing e-mobility.

Charging infrastructure is only one part of the holistic e-mobility system. Its characteristics, including charging protocols, outlets, power, location and accessibility, communication and control systems, and payment mechanisms all affect its value proposition and the cost/revenue model for its creation and operation. Whilst the RCN study has addressed only the financial value of rapid chargers, further work is being conducted through two EPSRC funded projects: the iBuild project (Newcastle University) to explore the wider value propositions for public EV charging infrastructure, and the LC Transform project considering the implications for fleet vehicle operations (Newcastle University, 2016).

Kley et al. (2011) described the EV value chain architecture and revenue model in terms of a morphological structure of infrastructure characteristics. Using this terminology, the RCN example is made up of a conductive power supply with high voltage AC and DC unidirectional connections, provided for public use by an energy utility operating the service to end customers, using metering at the charger but with no fees charged to the customer. Kley assumed that the majority of charging would be performed at home, and RCN research has confirmed this. The data loggers fitted to EV recorded the source of all energy received during the trial period, which was then categorized by type (Rapids, home, workplace, public 3/7 kW). 71% of energy was delivered by home chargers, but the second largest source 15.9% was found to be public rapid chargers (Blythe et al., 2015).² It is important to note that most of the UK's workplace and public recharging facilities were also free-to-use during the period of the RCN study.

Kley et al. also concluded that, in light of the limited business opportunity available, public charging infrastructure should be kept to a minimum and be provided by energy utilities funding it using home charging revenues. Although energy utilities do not operate many public chargers in the UK to date, Ecotricity operates a large proportion of the UK's public rapid charging on its Electric Highway, alongside its renewable energy supply business.

Schroeder and Traber (2012) provided an early insight into the return on investment available for public rapid chargers, identifying many of the set-up and operating costs likely to be incurred but concluding that market-driven rapid charging roll-out was fairly risky. More recent contributions have been made by Jochem et al. (2016) who investigated the optimal allocation of EVSE infrastructure along the German autobahn, and concluded that an economical rollout of fast charging infrastructure appeared feasible. However, this was based on several cost estimates which introduces uncertainty. The RCN business model removes this uncertainty by using actual UK CAPEX and OPEX costs coupled with actual EVSE usage data recorded along the highway. The RCN sensitivity analysis conducted between mark-up factor and demand at the EVSE also indicates that pricing will be very sensitive to demand, and suggests that surcharges (mark-ups) required to recover the investment costs will be higher than the 20% suggested by Jochem et al.

Literature stresses the importance of specifying the roles of each stakeholder in order to fully understand the value proposition for e-mobility business models. San Román et al. (2011) introduced two new market roles, the *EV Charging Manager* who develops charging infrastructure and the *EV Aggregator* who provides charging services using that infrastructure to end customers, EV drivers. These researchers concluded that public charging infrastructure should be provided by the *Distribution System Operator (DSO)* or *Distribution Network Operator (DNO)* in UK terms, with its costs covered in the same way as other grid expenditure. However, in the RCN UK example ZCF acted as EV Charging Manager in the UK, responsible for installing, owning and maintaining the chargers until December 2015 under an incubator model using a mix of public and private funds. Ecotricity acted as the UK EV Aggregator, engaging the sites, operating the chargers (providing electricity, customer support, back office and data management) and from 2016 took ownership of the assets and their associated costs going forward. Contrastingly ESB, a DSO, performed both EV Charging Manager and Aggregator roles for the Irish RCN chargers.

5. RCN business model

The RCN model follows the structure shown in Fig. 2. Using the terminology of Madina et al. (2016), Ecotricity and ESB each performed the role of *Electro-mobility Service Provider (EMSP)*,

² See page 37, figure 29.

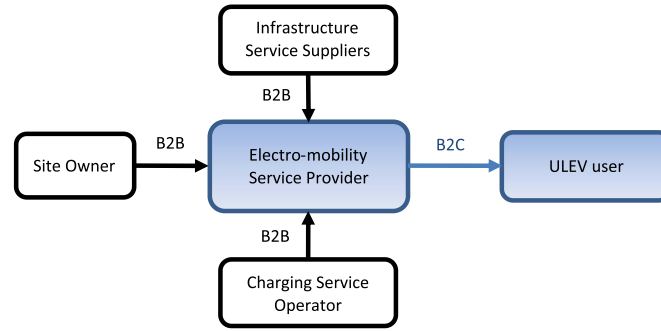


Fig. 2. Business model developed as a result of RCN.

providing recharging services to EV users on highways via a direct business to customer relationship (B2C). However, in order to do this the EMSP needs contractual business to business (B2B) relationships with the following stakeholders:

1. *Site owners*, from whom the EMSP rents the ground on which to install and operate the chargers. The EMSP may own sites with spare land in which case this relationship would be redundant. However, in RCN the owners of multiple motorway services, refuelling stations and retail sites fulfilled this role.
2. *Infrastructure Service Suppliers*. Although this may involve several functions, the EMSP requires suppliers to install chargers at each site. ZCF and its suppliers performed this role for RCN in the UK, including charger procurement, site surveys and planning permission, civil and electrical works, new power connections as well as the installation and commissioning of the chargers. In Ireland ESB performed this role. The EMSP's relationship with these stakeholders ends upon commissioning of the charger.
3. *Charging Service Operator*, who has the critical role of operating the charging equipment by providing the technical expertise, hardware and software necessary for the commercial exploitation of the recharging service by the EMSP.

The model developed here is for a single, multi-standard (three outlets) rapid charger with similar capabilities to those installed by RCN. The only revenue stream considered in this model comes from selling electricity to EV drivers. Additional sources of income and economies of scale may add value to the rapid charger investment, but those factors were outside the scope of this study since the RCN EMSP did not provide additional services at charger sites. As an example of the wider value opportunity available, the respondents to the RCN questionnaires reported to have spent £8.50 on average per charge event in nearby shops and cafes while waiting for their EVs to recharge (Blythe et al., 2015).³

6. Methodology

This methodology was developed to enable the RCN partners to investigate whether the necessary capital investment in rapid charging infrastructure, with its associated expenditures, can be recovered over a reasonable time in addition to making a return on capital which is sufficiently attractive for a prospective investor. The findings also have the potential to inform future policy on how government may need to intervene in the market to foster the roll-out of a suitable charging infrastructure to support the wider adoption of EVs by business and the public.

Fig. 3 illustrates the composition of costs and revenues incurred by

RCN and hence represents what potential investors in rapid charging infrastructure should consider. The initial capital expenditure (CAPEX) is incurred before operations begin totalling £38.4 K per charger on average. Once the charger is commissioned the investor starts to incur annual operating costs (OPEX) related to the operation and maintenance of the charger. A successful business model needs to create value both to the EMSP by providing a return on their investment, and to the EV user who takes advantage of the EMSP recharging service at a reasonable price.

The *Net Present Value* (NPV) of all capital inflows/outflows incurred throughout the lifetime of the project has been used as the basis to assess the investment potential. This is given by Eq. (1):

$$NPV = \sum_{n=0}^N p_n \cdot (1+i)^{-n} \quad (1)$$

where i is an interest rate (*discount factor*) reflecting the cost of capital and p_n the *net cash flow* (NCF) at the end of year n ; p_0 is the cash position up to the point where the charger is commissioned and, hence, is equal to the initial CAPEX. N is the *investment horizon* of the project which is determined by the *useful life* of the charger, taken to be 10 years based on communications with the manufacturer. The model also assumes for cost purposes that the charger is installed in 2015 (year 0) and will be generating revenue from 2016 to 2025.

The NCF at the end of year n follows as Eq. (2):

$$p_n = (s_n - c_n) \cdot (1-r) + d \cdot r \quad (2)$$

where s_n is the income derived from re-selling the electricity and c_n the aggregate of all the annual operating costs at the end of year n . The last term in the NCF equation includes d , a fixed depreciating charge estimated using a straight-line method and r , the prevailing corporation tax rate.

For a given year,⁴ denoted as n , the annual income is given by:

$$s_n = v_n \cdot x_n = v_n \cdot x_{n,0} (1+m) \quad (3)$$

with v_n being the amount of energy sold by the rapid charging outlet (in kWh) and x_n its re-selling price (in pence/kWh). The latter can be related to the electricity purchase price $x_{n,0}$, by using a *mark-up* factor, m .⁵ This model allows for all key variables changing year on year. The objective is to determine the *mark-up* factor, m , in Eq. (3) such that:

1. The investor breaks even at the end of the investment horizon. That breakeven mark-up factor will make the NPV in Eq. (1) equal to zero.
2. The investor makes a return on their investment of 15% as measured by the Internal Rate of Return (IRR) (Sullivan et al., 2015).

⁴ The equation represents the total annual revenue and assumes x_n is constant throughout the year. If purchase/re-selling prices change, the relationship needs to be calculated at transaction level, i.e. given that I transactions are carried out for year n , the annual revenue is given by $s_n = \sum_{i=1}^I v_{in} \cdot x_{in} = \sum_{i=1}^I v_{in} \cdot x_{in,0} (1+m)$.

⁵ e.g. when $m=0$ the electricity would be sold at its purchase price. When $m=1$ the energy would be sold at twice its purchase price and so on.

³ See page 63.

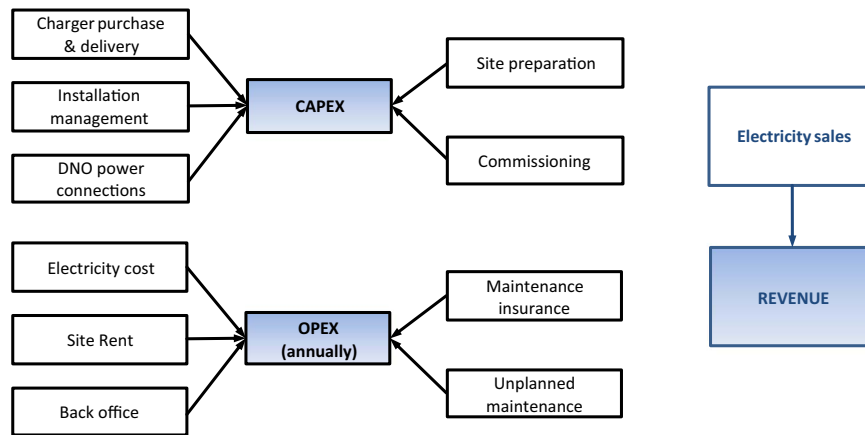


Fig. 3. Sources of costs and revenues arising from offering an EV battery recharging service. Revenues arise only from the sale of electricity.

Table 1
Summary of main model parameters.

Model parameter	Value	Section
Electricity purchase cost	9.8 p./kWh at baseline - rising 5.2% annually	Section 7.4
Energy demand at baseline (end 2015)	7500 kWh	Section 8.2
Planned maintenance cost	3% charger cost per year	Section 7.3
Unplanned maintenance cost	4% charger cost per year	Section 7.3
Charger salvage value	5% charger per year	Section 7.6
Discount factor	5%	Section 7.6
Inflation rate	Rises 2% annually	Section 7.6
Availability factor	50%	Section 7.6

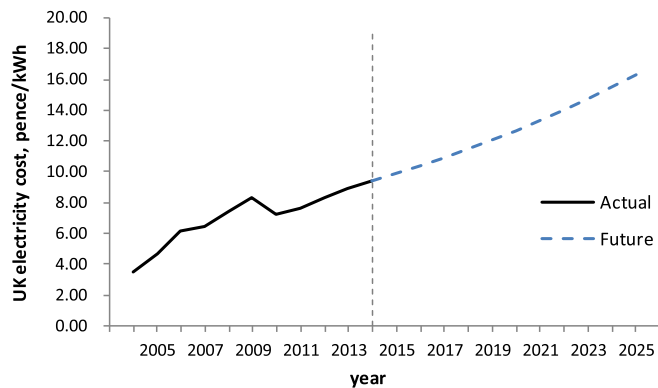


Fig. 4. UK electricity prices (excluding Climate Change Levy) for non-domestic consumers between 2004 and 2014. Projection up to 2015 uses a 5.2% annual compound growth rate.

7. Data and input parameters considerations

7.1. Data

The CAPEX and OPEX figures used in this study reflect the actual costs of installing and running 68 rapid chargers across 58 UK sites during 2014 and 2015 as part of the RCN project (RCN, 2014). The values used for each model parameter are summarised in Table 1. Further background on these parameters can be found in the following sections indicated.

7.2. CAPEX

As illustrated in Fig. 4, RCN incurred the following capital costs:

1. *Charger purchase & delivery.* These costs refer to the multi-standard chargers purchased in RCN, incorporating 3 outlets and 3 years warranty. Chargers were delivered to local storage facilities where tests, upgrades and branding were carried out. This delivery cost varied by country.
2. *Installation project management.* Related to managing all on-site work including surveys, planning permission, building warrants, physical works etc. This is a vital role, coordinating all stakeholders including the site operator, land owners, DNO costs where new power connections are required, civil and electrical subcontractors, commissioners etc.
3. *New power connections.* Incurred whenever a new power connection from the charger to the local electricity distribution grid is required. These costs are location-dependent and vary with the power required, length of the cable run and transformer requirements. The EMSP owns new power connections and ensures that individual meters are installed to record electricity use. In the UK the cost is dictated by the single DNO licensed to distribute electricity from the transmission grid to businesses in that area (OFGEM, 2016). New power connections were required at 15 (26%) of RCN sites and varied in price from £1000 to over £20,000.
4. *Site preparation works.* All civil and electrical engineering work required to install the charger including excavation, cabling, plinths, feeder pillars, associated switchgear and metering equipment, bay marking, signage etc.
5. *Commissioning.* Costs related to delivering EVSE from local storage

facility to site, connecting to power, limited communication test, function and safety checks. This service was performed by a single subcontractor to ensure conformity.

7.3. OPEX

The annual operating expenses can be broken down as follows:

1. *Electricity cost.* The cost of the energy used by the chargers and delivered to EV users to recharge their vehicle battery. The amount of energy used by each charger was recorded by a meter unique to each electricity supply point.
2. *Site rent.* All RCN chargers were installed on existing sites and no land purchase was required. The EMSP pays a rental fee to the existing site operator.
3. *Back office running costs.* These include all the expenses related to management of charger and user-related costs: user registration, issuing of RFID cards, provision of online user account capabilities and customer support services. It also includes fees for software provision, upgrades, development etc. All this functionality can be outsourced.
4. *Maintenance costs.* This covers routine checks, but also establishes call-out arrangements, stocks of spare parts etc. to ensure that the EMSP has ongoing support. The service must be provided by a supplier trained and approved by the charger manufacturer.
5. *Unplanned maintenance costs.* Set at 4% of the charger purchase and delivery costs to allow for unexpected contingencies such as vandalism and non-warranty part failure. This figure is based on practical experience of over 200 rapid charger installations over 3 years in the UK.

7.4. Electricity costs

In 2004 a UK non-domestic user (medium size in terms of energy consumption) paid 3.5 pence per kWh of electricity, whereas in 2014 the same customer paid 9.4 pence (Department of Energy and Climate Change, 2015). This change represents an annual compound growth rate of 10.4%. The RCN model assumes that the price the EMSP will have to pay for its energy will grow annually to 2025 at half the historical rate i.e. at 5.2% (Fig. 4).

7.5. Electricity re-sale mark-up ceiling

The Office of Gas and Electricity Markets (OFGEM) is the UK's independent national regulatory body responsible for protecting the interests of UK energy consumers. However, OFGEM only directly regulates the cost of running the energy transportation networks which are delivered by monopoly DNO businesses in the UK. Although OFGEM gives EMSPs in the UK the freedom to set the price for the electricity they resell through EV chargers (OFGEM, 2014), most authors envisage that there will be a maximum price which EV users are willing to pay. To calculate this maximum price we have assumed it equates to the running costs of an ICE vehicle, resulting in a maximum mark-up factor of 3.3 for the electricity re-sale price. This value includes a 40% contingency factor to the average fuel consumption of new vehicles sold in the UK in 2014 in line with reported figures (Tietge et al., 2015) and uses an average fuel price of 106 pence/litre. The calculation uses RCN's measured electricity consumption figure of 18 kWh/100 km (Wardle et al., 2015) and assumes that the EMSP pays 9.8 pence/kWh for the electricity they resell.

Although during RCN the electricity was delivered free to EV drivers, RCN questionnaire results indicated that 65% of respondents

were willing to pay to use rapid chargers, with most of those reporting a preference to pay per recharge based on the energy used. Regarding the fees respondents were willing to pay, over 64% stated they would pay £0.16 per kWh, reducing to only 1% willing to pay £0.40 per kWh. 70% of respondents knew how much it cost them to recharge at home, and 37% stated that they would be willing to pay for rapid charging only if they had no alternative way to charge. But only 0.6% stated they would switch back to an ICE vehicle if fees were applied to public rapid chargers. This evidence suggests that EV drivers who understand the cost of recharging may change their behaviour to minimise cost, a risk which EMSP's should consider in setting fees without losing significant customer base. However, RCN respondents also stated that the main reasons for rapid charger use were that they 'needed to make a longer journey' (59%) and 'need to charge fast' (28%) and over 93% of the respondents stated that they had travelled further and 61% more often by EV, due to the availability of rapid chargers. This suggests that rapid chargers located where drivers need to recharge quickly to extend journey distances are likely to support higher fees. Availability and reliability of the recharging service are likely to become the most valued aspects of the EMSP's offering in these locations.

7.6. Other parameters

The following assumptions have also been made:

1. *Charger salvage value.* At the end of its operational life the charger is assumed to have a market price of 5% of its total purchase price.
2. *Interest rate (discount factor)* or capital costs for the investor of 5%.
3. *Annual inflation rate.* All annual OPEX costs are assumed to increase at a rate 2% per year, except for energy costs assumed to grow at 5.2% as mentioned earlier.
4. *Charger availability factor.* This is required to determine the annual charger capacity (kWh/year) in order to make revenue estimates. It represents the percentage of time we expect the charger to be in use over a year. RCN data indicates periods of very low demand overnight, plus idling time between charges and some downtime. Therefore, this parameter has been conservatively set at 50% where it does not have an effect on the model output until the annual growth rates in energy demand are greater than circa 28%.

8. Results

The two main parameters which determine the strength of the investment decision are the electricity re-sale price and the volume of energy expected to be sold at the EVSE. This relationship is fully explored in this section along with the impact that fiscal policies can have on the potential return that investors may expect.

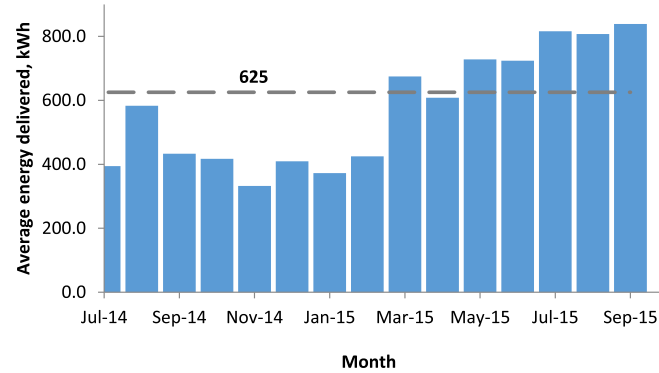
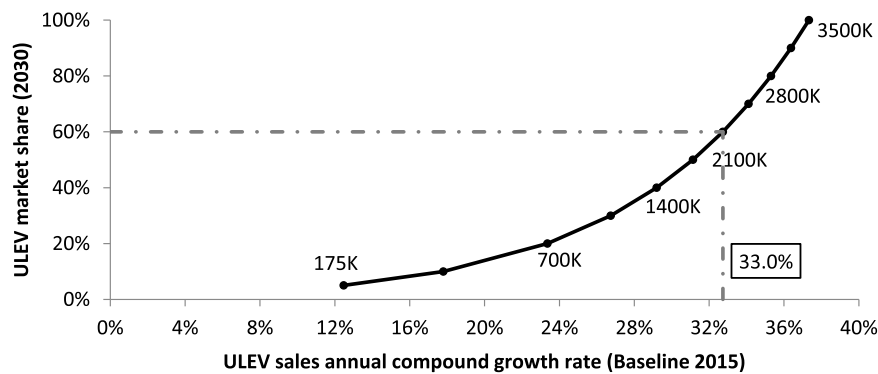
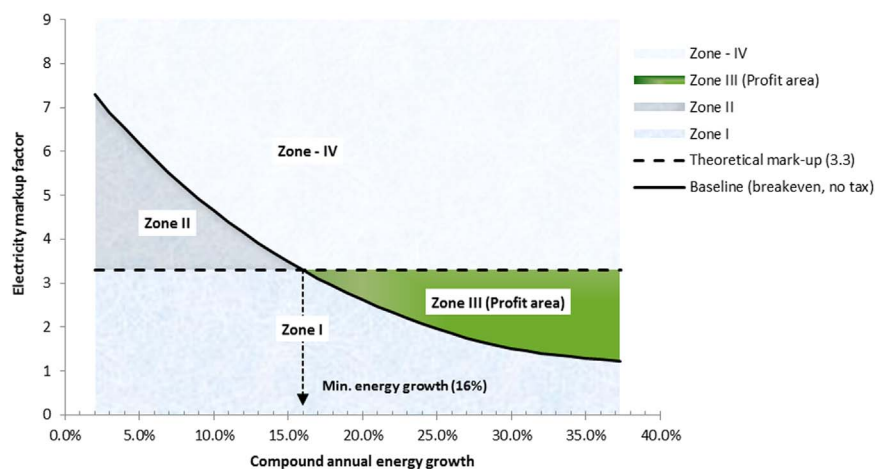
8.1. Capital expenditure

On average, an investor in multi-standard rapid-charging infrastructure is expected to make an initial CAPEX investment of at least £36,500 per charger without new power connections required, rising to circa £42,000 when new power connections are required. The magnitude of each CAPEX component as a percentage of the total fixed capital investment is shown in Table 2. Each row represents a different scenario. Row A reflects the global average across the project regardless of whether a site required new power connections (shown in row B) or not (row C). The main CAPEX components are the charger cost at up to 57% of the initial investment, and the preparation of the site at up to 32%.

Table 2

Cost breakdown as a percentage of the total CAPEX.

	Charger Purchase & Delivery	Installation & Commissioning Management	New Power Connections	Site Preparation Works	Commissioning
A: all sites	54.7%	7.7%	4.3%	30.4%	2.9%
B: sites with NPC	49.9%	7.0%	14.2%	26.3%	2.7%
C: sites without NPC	57.2%	8.1%	0.0%	31.7%	3.1%

**Fig. 5.** Average monthly energy delivered per charger-month in RCN. Horizontal line represents the initial energy demand assumed for modelling purposes and represents the average energy demand delivered since the project inception.**Fig. 6.** Annual compound growth rate in ULEV sales required (from 2015) to achieve a given market share in 2030. Data labels represent ULEV projected sales (in thousands) in 2030. Vertical line at 60% ULEV market share illustrates the case under the CCC's Central CO₂ abatement scenario.**Fig. 7.** Identification of the electricity mark-up factor/energy growth needed to achieve a self-sustaining business case under the baseline scenario (no corporation tax where investment breaks even).

8.2. ULEV growth scenarios

The second key parameter affecting return is the volume of energy v_n sold at the charging station, as shown in Eq. (3). RCN data has been

used to determine v_0 , i.e. the baseline energy demand immediately after the charger was commissioned. As shown in Fig. 5, demand across the network increased from circa 400 kWh/charger-month in July 2014 to approximately 840 kWh/charger-month at the end of September

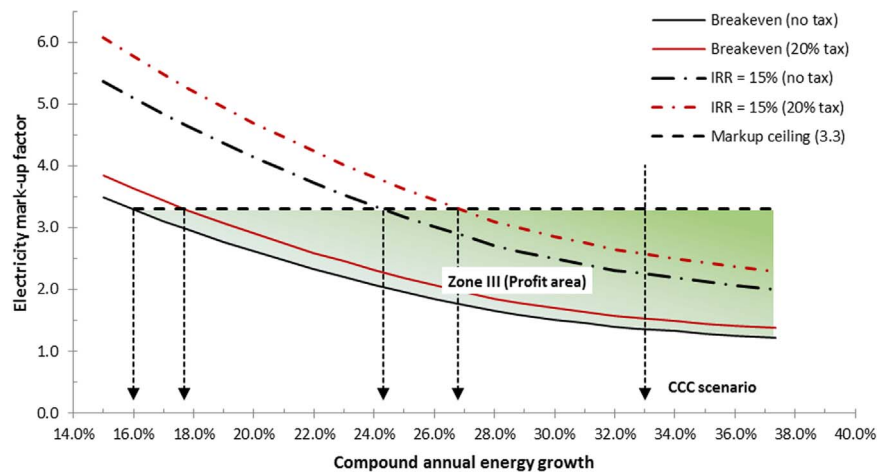


Fig. 8. Electricity mark-up factors required for a profitable investment under different demand growth scenarios, with and without UK corporation tax. Shaded area highlights the most desirable working range (where positive return on investments can be achieved).

2015.⁶ Although starting from a low figure, this change represents a growth of circa 90% in annual terms. The average energy delivered per charger per month since project inception amounted to 625 kWh/month, which has been used as a conservative baseline estimate for v_0 .

To estimate v_1, \dots, v_{10} , we make the assumption that the energy demand throughout the lifetime of the investment will grow at the same rate as ULEV sales. In order for the UK to meet its legally binding target for greenhouse gas reduction, the UK CCC has set a central CO₂ abatement scenario for transport where ULEV market share reaches 60% by 2030 (Committee on Climate Change, 2015). That target would translate into 2.1 million new ULEV sold in 2030 from an expected total of 3.5 million vehicle sales (Element Energy, 2013). Given that in 2015 UK annual ULEV sales were 29,963 (DfT, 2015), this would require an annual compound growth rate of circa 33%, which is well below that experienced in 2014 and 2015. This is shown graphically in Fig. 6 which illustrates the relationship between year on year constant compound growth rates and ULEV market share by 2030.

8.3. Business case – sensitivity analysis

Rather than focusing on individual future projections for energy demand, the approach taken here considers the full spectrum of annual growth rates, enabling an investigation into the combinations of ULEV growth rate and energy resale price required to make an acceptable return. This analysis can be achieved by concurrently running Eqs. (1)–(3) and fixing a combination of two of the three key model parameters, namely the electricity mark-up, the annual growth rate at the EVSE and the IRR. Fig. 7 is an example of this strategy where the IRR has been set so that the business breaks even in an environment with no corporation tax (the baseline scenario). The equations are then solved iteratively for the third variable across the full range of energy growth rates. This baseline scenario establishes the minimum electricity mark-up factor required for the business to recover its initial investment and results in a curve that decreases monotonically from high mark-ups at low energy demand, to lower mark-ups as the energy growth increases.

When this curve is plotted alongside the theoretically-derived mark-up ceiling, the graph splits into four distinct areas:

1. *Zone I* – the area below the breakeven curve and the mark-up ceiling, whichever is lower. In this zone electricity mark-ups are insufficient to make the business break even at the given energy growth rate.
2. *Zone II* – in the upper left area of Fig. 7 even though electricity

mark-up factor is higher than the mark-up ceiling, the energy growth rates at the EVSE are insufficient to make the EMSP business break even.

3. *Zone III* – characterized by electricity mark-up below the theoretical mark-up ceiling but above the breakeven line, with sufficient energy demand to allow for a profit. EMSP businesses should seek to operate in this zone in order to be self-sustaining.
4. *Zone IV* – where electricity mark-ups are above both the breakeven line and the mark-up ceiling. Operating in this area will lead to a profit, but it is unlikely to be sustainable in the long term due to EV users' reluctance to pay recharging prices which are higher than ICE costs and increased competition entering the marketplace.

Fig. 7 also illustrates that, irrespective of mark-up, viable business propositions are likely to require annual energy growth rates above approximately 16%.

8.4. Characteristics of Zone III – the profit area

To investigate the effect of fiscal policy on the profit area, three scenarios have been plotted against the baseline in Zone III, as presented in Fig. 8:

- (1) The EMSP business breaks even with no tax incentives (i.e. a 20% corporation tax applies to profits);
- (2) The EMSP achieves a commercial IRR of 15% operating under a fiscal incentive with no tax applied for investment in rapid-charging infrastructure;
- (3) The EMSP achieves an IRR of 15% under a 20% corporation tax regime.

Investments made under current corporation tax rules (20%) lead to a progressive and non-linear shrinkage of the optimal profitable conditions. Investors will require progressively higher levels of growth in energy demand to break even over the 10 year period in each scenario, from 16% in the baseline case to circa 18% in scenario (1), 24% under scenario (2) and 27% in scenario (3). These are all considerable annual growth rates below which it is very unlikely that the purpose of the investment decision will be met.

If the CCC's central CO₂ abatement projections of 33% annual growth in ULEV sales are met by 2030 Fig. 8 shows that all 3 scenarios fall inside the profitable area. At this growth rate investors could achieve IRR up to 23% (without tax) over 10 years by selling the energy at the maximum mark-up factor of 3.3. A minimum mark-up factor of 1.4 would be required to break even under the baseline scenario. However, if the CCC's growth targets are not met it is still possible to

⁶ RCN chargers began operating on various dates throughout 2014 and 2015. As an example, averages in July 2014 are based on data from 8 chargers while averages in September 2015 are based on 40 chargers.

achieve IRR 15% with zero corporation tax and circa 24% market growth in energy, as shown by the intersection of mark-up ceiling line and scenario (2) curve.

9. Conclusion and policy implications

This research uses real-world EVSE cost and usage data from the RCN project to provide insights into the economics of a privately funded roll-out of rapid charging infrastructure on main highways. Using real world data we have concluded that investment in EVSE rapid chargers providing Mode 3 and 4 conductive charging services on main highways is viable, and we have identified the operating area in which a profit can be made by EMSPs. The figures presented in this paper reflect the position in the UK in 2016 and we recognise that the value of parameters will differ between countries and over time. However this method serves as a model for others to use to make business and policy decisions.

The biggest uncertainty facing private investors in this evolving marketplace is the energy demand expected over the investment period, which depends directly on ULEV adoption. The RCN model suggests that if the CCC's target of 60% ULEV market share is to be reached by 2030 there is a good opportunity for investment in rapid charging in the UK beginning now, with electricity sold at a mark-up factor of 3.3 through the EVSE. However, this represents a significant increase in ULEV adoption, which needs to be sustained long term to produce the energy demand growth rates required to make the EVSE investment attractive (18% to break-even and 27% to make a return of 15%). Furthermore, if ULEV drivers are unwilling to pay the 3.3 mark-up suggested by this research then even bigger energy growth rates will be required to make private investment profitable. EMSPs should also consider that rapid EVSE will draw new business to the locations where they are installed, so additional revenue may be generated from non-electricity sales which could boost the case for investment further.

The UK has experienced high growth in ULEV adoption rates to date, but despite the incentives provided, uptake (1.2% of new car sales) still lags behind other more successful European countries. ULEV is still in the first Innovators stage of adoption according to the Diffusion of Innovations theory (Rogers, 2003), where the technology is viewed by many consumers as disruptive to routine tasks, and therefore inferior to the existing ICE technology. However, ULEV adoption is critical to the UK government's emission reduction targets, requiring 9% of new car sales to be ULEV by 2020 which represents a move into the Early Adopter phase. Achieving the 60% target set for 2030 represents a shift through the Early Majority and into Late Majority adopter phases, where consumers will require the new ULEV technology to at least match performance of the existing ICE technology. This would represent the onset of a new regime in transport systems according to Technological Transitions theory (Geels, 2002).

The UK government's stated objective, to see a UK car fleet with effectively zero emissions by 2050, is driven by both emission reduction targets and the desire to maximise UK business opportunity in the ULEV sector. In order to achieve this goal, the ULEV market must develop rapidly beyond its current niche status. Radical innovations in technology, user practices, supporting infrastructure and functionality are still required to increase ULEV adoption, which is difficult to achieve when faced with the challenges of the existing well-developed and improving ICE market. All of which creates uncertainty for potential EVSE investors.

Therefore we suggest that the ULEV market in the UK requires protection from ICE market pressures in the form of clear and fixed financial incentives towards vehicles and public EVSE until at least 10% ULEV adoption has been achieved. For EVSE, this may take the form of tax benefits for EMSPs rolling-out rapid charging infrastructure, as well as capital subsidies.

This should then be followed by a clear and progressive incentive reduction programme, to be informed by regular review and feedback,

to ensure that the ultimate objectives of ULEV roll-out, emissions reduction and UK business development, are being reached. Assessing the results of actual ULEV adoption against this holistic goal should also help to avoid the market failure which some commentators suggest will be the long term result of the continued public subsidy of charging infrastructure.

This study proves that a credible financial business case does exist for further investment in rapid charging infrastructure in the UK, if drivers are willing to pay 3.3 mark-up on electricity prices. However, it also proposes continuing financial incentives to protect investors from uncertainties in the marketplace. Due to the risks associated with continuing technological development, consumer acceptance and drivers' willingness to pay the mark-up required, alternative solutions focussing on wider non-financial value should also be investigated.

The RCN study's basis, using real-life costs and usage data alongside targeted ULEV adoption figures with corresponding increases in energy demand, provides a significant contribution to both the academic and governmental debate about whether countries can sustain growth in ULEV adoption by delivering a suitable public charging infrastructure to create and retain the confidence of drivers to purchase ULEVs. With issues of both greenhouse gas reduction and mitigation of road-based traffic congestion, the political will for encouraging and facilitating ULEV uptake clearly exists in the UK and has been explicitly reiterated by the new Government. Uncertainty over the funding of publically available infrastructure has been seen as one of the most significant barriers and risks to future widespread adoption of ULEV. The business case presented here will assist governments and private investors to understand that, with careful policy support, a business case does exist.

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References

- ACEA, 2015. Electric and Alternative Vehicle Registrations.
- Bakker, S., Trip, J.J., 2013. Policy Options to support the adoption of electric vehicles in the urban environment. *Transp. Res. Part D* 25, 18–23.
- Bakker, S., Maat, K., van Wee, B., 2014. Stakeholders interests, expectations and strategies regarding the development and implementation of EV: the case of the Netherlands. *Transp. Res. Part A* 66, 52–64.
- Blech, T., Kozdra, N., 2016. Fast chargers for all: multistandard charger deployment and usage in Europe EVS29 Symposium, Montréal, Québec, Canada.
- Blythe, P.T., Neaimeh, M., Serradilla, J., Pinna, C., Hill, G., Guo, A., 2015. Rapid Charge Network Activity 6 Study Report. Newcastle University (http://rapidchargenetwork.com/public/wax_resources/RCN%20Project%20Study%20Report%20Digital.pdf).
- Bohnsack, R., Pinkse, J., Kolk, A., 2014. Business models for sustainable technologies: exploring business model evolution in the case of electric vehicles. *Res. Policy* 43, 284–300.
- Committee on Climate Change, 2008. Building a low-carbon economy - the UK's contribution to tackling climate change. TSO@Blackwell.
- Committee on Climate Change, 2015. Sectoral Scenarios for the fifth carbon budget, London.
- Davies, W., Santos, G., Faye, I., Kroon, R., Weken, H., 2016. Establishing the transferability of best practice in EV policy across EU borders. *Transp. Res. Proc.* 14, 2574–2583.
- Department for Transport, 14 2016. Vehicle Licensing Statistics: Quarter 4 (Oct-Dec) 2015. In: Transport, D.f. (Ed.).
- Department for Transport, Q3, 2016a. veh0130 ULEV licensed.
- Department for Transport, Q3, 2016b. veh0150 Vehicles registered for the first time Vehicles statistics.
- Department of Energy & Climate Change, 2015. Gas and electricity prices in the non-domestic sector, Table 3.4.1, Industrial energy price statistics.
- DfT, 2015. Vehicles registered for the first time by body type, Great Britain, monthly

- from 2001 (Table VEH0150), In: Transport, D.f. (Ed.), Vehicle Statistics.
- European Commission, Infrastructure - TEN-T - Connecting Europe, (http://ec.europa.eu/transport/themes/infrastructure/index_en.htm).
- Element Energy Pathways to high penetration of electric vehicles for The Committee on Climate Change 2013.
- ELMO, ELMO Programme - Electromobility in Estonia, (<http://elmo.ee/home/>).
- ESB, ESB ecars, URL (<https://www.esb.ie/our-businesses/ecars/about-esb-ecars>).
- European Commission, 2013. Clean Power for Transport.
- European Commission, 2014. Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure [2014] OJ L307/1.
- Franke, T., Krems, J., 2013. Understanding charging behaviour of electric vehicles users. *Transp. Res. Part F* 21, 75–89.
- Geels, F., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Res. Policy* 31, 1257–1274.
- Gnann, T., Plotz, P., Kuhn, A., Wietschel, M., 2015. Modelling market diffusion of electric vehicles with real world driving data - German market and policy options. *Transp. Res. Part A* 77, 95–112.
- Haugneland, P., Bu, C., Hauge, E., 2016. The Norwegian EV success continues, EVS29, Montreal, Quebec, Canada.
- Herron, C., Wardle, J., 2015. In: Filho, Walter Leal, Kotter, R. (Eds.), *Technology Trajectory and Lessons Learnt from the commercial introduction of EV in North East England. E-Mobility in Europe Trends and Good Practice*, 161–178.
- Hübner, Y., Blythe, P., Hill, G., Neaimeh, M., Austin, J., Gray, L., Herron, C., Wardle, J., 2013. 49,999 Electric car journeys and counting. EVS27, Barcelona.
- Jochem, P., Brendel, C., Reuter, M., Fichtner, W., Nickel, S., 2016. Optimizing the allocation of fast charging infrastructure for electric vehicles along the German Autobahn. *J. Bus. Econ.* 86 (5), 513–535.
- Kley, F., Lerch, C., Dallinger, D., 2011. New business models for electric cars—A holistic approach. *Energy Policy* 39, 3392–3403.
- Madina, C., Zamora, I., Zabala, E., 2016. Methodology for assessing electric vehicle charging infrastructure business models. *Energy Policy* 89, 284–293.
- Markkula, J., Rautiainen, A., Jarventausta, P., 2013. The business case of electric vehicle quick charging: no more chicken or egg problem. *Electr. Veh. Symp. Exhib. (EVS27)*, 2013World, 1–7.
- Newcastle University, 2015. iBUILD Project (Infrastructure Business models, valuation and Innovation for Local Delivery), URL (<https://research.ncl.ac.uk/ibuild/>).
- Newcastle University, 2016. LC Transform Project (Low Carbon Transitions of Fleet Operations in Metropolitan Sites).
- Office for Low Emission Vehicles, 2010. Plugged in Places.
- Office for Low Emission Vehicles, 2011. Plug-in Car Grant, (<https://www.gov.uk/government/publications/plug-in-car-grant>).
- Office for Low Emission Vehicles, 2013. Driving the Future Today - A strategy for ultra low emission vehicles in the UK, In: OLEV (Ed.), London.
- Office for National Statistics, 2016. Public attitudes towards electric vehicles: 2016 (Revised) In: Department for Transport (Ed.).
- OFGEM, 2014. Direction issued on 14 March 2014 on the Maximum Resale Price (MRP) of Gas and Electricity.
- OFGEM, 2016. The GB electricity distribution network.
- OLEV, 2016. Grant schemes for electric vehicle charging infrastructure.
- RCN, 2014. The Rapid Charge Network Project.
- Rogers, E.M., 2003. *Diffusion of Innovations* 5th edition. Simon and Schuster.
- San Román, T.G., Momber, I., Abbad, M.R., Sánchez Miralles, Á., 2011. Regulatory framework and business models for charging plug-in electric vehicles: infrastructure, agents, and commercial relationships. *Energy Policy* 39, 6360–6375.
- Schroeder, A., Traber, T., 2012. The economics of fast charging infrastructure for electric vehicles. *Energy Policy* 43, 136–144.
- Sierzchula, W., Bakker, S., Maat, K., Van Wee, B., 2014. The influence of financial incentives and other socio-economic factors on electric vehicle adoption. *Energy Policy* 68, 183–194.
- SLAM project, Quick charger for axes and cities, In: Bundesministerium für wirtschaft und energie (Ed.), (<http://www.slam-projekt.de/index.php>).
- Sullivan, W.G., Wicks, E.M., Koelling, C.P., 2015. *Engineering Economy* 16 ed.. Pearson.
- Tietge, U., Zacharof, N., Mock, P., Franco, V., German, J., Bandivadekar, A., Ligterink, N., Lambrecht, U., 2015. A 2015 Update of Official Real World Fuel Consumption and CO2 values for Passenger Cars in Europe, In: ICCT(Ed.), *From Laboratory to Road*.
- Wardle, J., Bramich, A., Neaimeh, M., Serradilla, J., Pinna, C., Hill, G., Guo, W., Blythe, P.T., 2015. Rapid Charge Network: breaking down the barriers to longer distance electric driving, European Battery, Hybrid and Fuel Cell Electric Vehicle Congress, Brussels, Belgium.